Radio Broadcast Coverage of City Areas [1]

By LLOYD ESPENSCHIED

SYNOPSIS: 1. Radio broadcasting involves a system of electrical distribution in which dependent relations exist between the transmitting station, the transmitting medium and the receiving station.

2. The attenuation and fading which attend the spreading out of broadcast waves are considered. The attenuation of overland transmission is shown to be, on the whole, very high and to vary over a wide range depending upon the terrain which is traversed. The distance at which the fading of signals occurs is found to be that at which the normal directly transmitted waves have become greatly attenuated and to depend upon the terrain traversed.

3. A field strength contour map is given of the measured distribution of waves broadcast by Station WEAF over the New York metropolitan area. A rough correlation is given between measured field strengths and the serviceability of the reception in yielding high grade reproduction. The range of a station as estimated in terms of year-round reliability is found to be relatively small. It becomes clear that the present radio broadcasting art is upon too low a power level and that higher powered stations are required if reliable year-round reception is to be had at distances as short even as 30 to 50 miles from the transmitting station.

4. The question of the preferred location of a transmitting station with respect to a city area is considered. It is shown that an antenna located upon a tall building may radiate poorly at certain wave-lengths and well at others. Surveys are presented of the distribution effected by an experimental transmitting station located in each of several suburban points. The locations are compared upon the basis of the "coverage" of receiving sets which they effect.

5. Finally, there is considered the relation which exists in respect to interference between a plurality of broadcast transmitting stations operating in the same service area. The importance of high selectivity in receiving sets is emphasized and there is given the measured selectivity characteristics for samples of a number of receiving sets.

IT is well recognized that the elements which comprise an electrical transmission system are required to function not simply as individual pieces of apparatus, but as integral parts of a whole. In the case of radio broadcasting, the absence of a common control of the two ends makes this over-all "systems" aspect less apparent than it is for wire systems.[2] Nevertheless a definite systems correlation is required between the broadcast transmitting station and each of the receivers served, as will be evident from the following:

1. The transmitter should put into the transmitting medium, without distortion and with the power called for by that medium, all of the wave-band components required and no others.

2. The transmitting medium should be capable of delivering to the receiver an undistorted wave band, reliably and stably, and with

[1] Presented at the New York Regional Meeting of the A. I. E. E., New York, N. Y., Nov. 11–12, 1926.

[2] Some other examples of such a "systems" relationship are given in "Application to Radio of Wire Transmission Engineering," published in the *Proceedings* of the Institute of Radio Engineers, October, 1922.

sufficient strength to enable the received waves to stand well above the level of the ever present interfering waves.

3. Finally, the receiving set should pass with the necessary volume all of the wave components required to reproduce the program signal and should sharply exclude all others.

The rapid apparatus development borne in by the vacuum tube has brought the art to the point where it is now physically possible to meet quite fully the terminal requirements. The apparatus development, in fact, has outstripped our knowledge of the transmitting medium itself, and we are now in the position of possessing apparatus possibilities without knowing very definitely the limitations and requirements placed upon their use by the intermediate link. Only within the last few years have methods become available for measuring radio transmission and thereby placing it upon a quantitative basis.

Such measuring means have been applied to the study of radio broadcast transmission from certain stations in New York City and in Washington, D. C. The earlier results of this measurement work have already been published. It is the purpose of the present paper to present results of a systematic study which has been made of the coverage which can be effected of the radio broadcast listeners of the New York metropolitan area and in so doing to portray something of the general systems requirements of radio broadcasting.

The Character of Radio Broadcast Transmission

The ideal law for broadcast distribution would be one whereby the transmitted waves are propagated at constant strength over the zone to be served and then fall abruptly to zero at the outer boundary. All receivers within the area would be treated to signals of equal strength and no interference would be caused in territories beyond.

The kind of law which nature has actually given us involves a rapid decadence in the strength of the waves as they are propagated over the service area, and then, instead of a sharp cut-off, a persistence to great distances at field strengths which, although often too low to be generally useful, are sufficient to cause interference in other service areas.

This situation is illustrated in Fig. 1. The upper curve shows the relation between intensity and distance; the lower portion, the interpretation of this curve in terms of areas of reception. The attenuation traced by the heavy line of the curve is that of the component of the radiation which is propagated directly along the earth's surface. It is this radiation which is ordinarily utilized for reliable broadcast reception. The shaded portions near the outer ends of this curve are

intended to indicate the appearance of variations in the signal intensity which occur at the greater distances, particularly at night, and which are known as "fading."

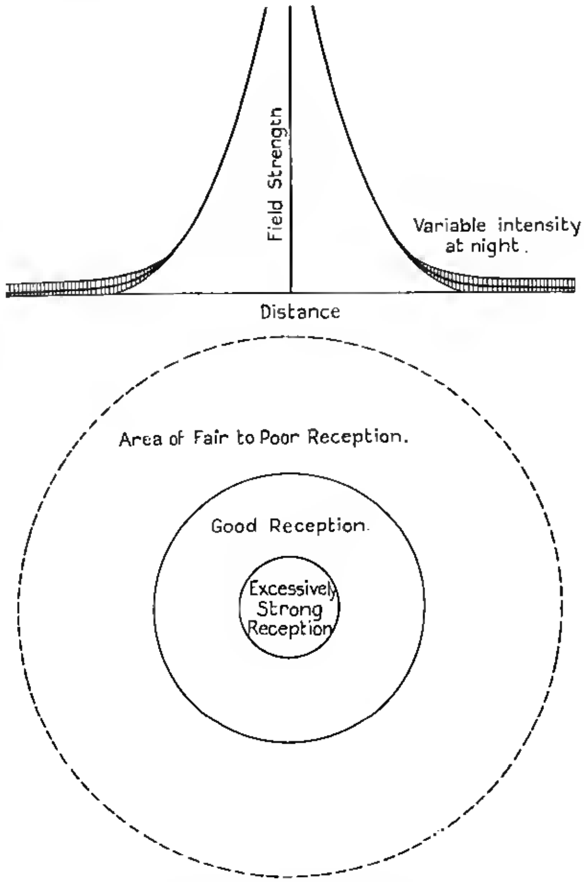

Fig. 1—The attenuation of broadcast waves in reference to the areas served

The evidence of recent researches, particularly those made at short wave-lengths, indicates that these fading variations are due to radiant energy which has left the earth's surface at the radio transmitter and has been reflected or refracted back to the earth's surface from a conducting stratum in the upper atmosphere. At broadcast frequencies the reflected wave component is observed at night but has not been noticed during the day. At locations close to the transmitting station the effect of the reflected component is negligible as compared with the strength of the directly transmitted waves. At

increasing distances the directly transmitted waves die away to very low values and the indirectly transmitted waves begin to show up and appear to become controlling at the longer distances. The fluctuations themselves appear to be due in part, if not entirely, to variations in the reflected waves themselves, resulting perhaps from fluctuations in the conditions of the upper atmosphere.

Thus, it seems clear that radio transmission involves wave components of two types: one which delivers directly to the receiving area immediately surrounding a broadcast station, a field capable of giving a reliable high grade reception; and another transmitted through the higher altitudes which permits distant reception but not with the reliability and freedom from interference required of high grade reproduction.

The effects which are actually realized in practice are indicated in a more quantitative manner by the curves of Fig. 2 which are plotted from some measurements made upon WEAF in New York and WCAP in Washington, D. C. They were made at locations in the New York and the Washington areas and at the intermediate points

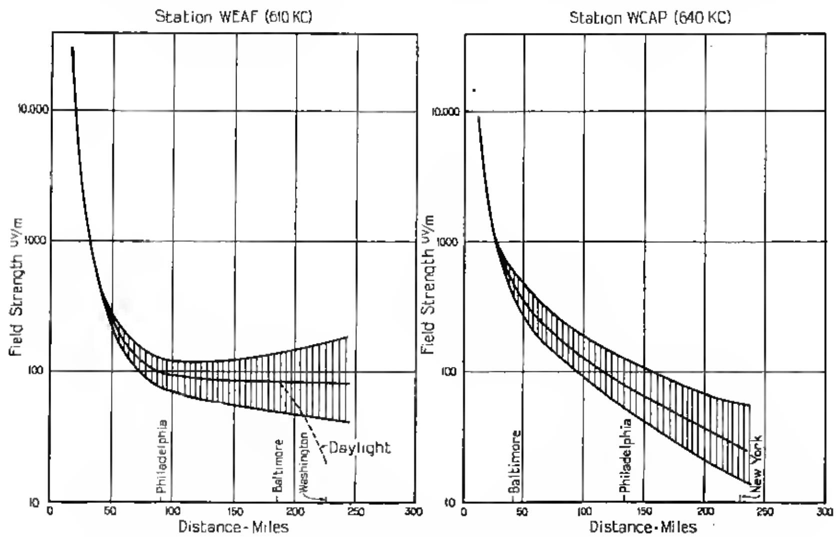

Fig. 2—Results of a few measurements upon the reduction in field strength with distance, including distances at which fading occurs

indicated on the curves. The measurements at each of these points are for one day only. They consisted in obtaining continuous graphic records of signal intensity during twenty-minute intervals out of each hour, one interval for each of the two stations. The period of time

covered for each set of measurements was that of from one hour before sundown to about three hours after sundown. The time of year was the latter part of May, 1926. The curves are plotted from an analysis of the records in terms of mean field strength. The range of variation due to fading is indicated by the shaded portions of the curves. The day and night fields were found to be roughly the same except for WEAF where there is a material drop in the daytime signal between Baltimore and Washington, shown in the WEAF curve.

Fading was observed to commence somewhere between 50 and 100 miles from the stations and the range of the fluctuations was found to increase up to the maximum distance observed. That the field of WEAF was found to be practically as strong at Baltimore as at Philadelphia is surprising. The data regarding this point are too meager, however, to enable any very definite conclusions to be drawn. The curves are useful principally in enabling the transition to be followed, in a more quantitative way than is done in Fig. 1, from field strengths capable of giving reliable reception, such, for example, as 10,000 μv./m. (microvolts per meter), to those which characterize the unreliable "distance" reception and are of the order of 100 μv./m.

A fact which is of importance to our understanding of these wave phenomena is that "fading," which ordinarily is noticed at distances of the order of 100 miles, may under some conditions become prominent at distances as short as 20 miles from the transmitting station. Such short-distance fading has been experienced in receiving WEAF in certain parts of Westchester County, New York.[3] It appears to be a case where unusually high attenuation, caused by the tall building area of Manhattan Island, has so greatly weakened the directly transmitted wave as to enable the effect of the indirect wave component to become pronounced at night.

In general, the attenuation suffered by the normal surface-transmitted waves varies over wide limits depending upon the terrain which is traversed. This is disclosed by the curves of Fig. 3, which show the drop in field strength with distance, for a 5 kw. station, for each of the following conditions:

a. No absorption, the inverse distance curve ($\alpha = 0$),

b. Sea water, for which the absorption is relatively small ($\alpha = 0.0015$),

c. Open country and suburban areas ($\alpha = 0.02$ to 0.03) as measured in the vicinity of New York and Washington, D. C.,

d. Congested urban areas ($\alpha = 0.04$ to 0.08) as measured for Manhattan Island.

[3] See "Some Studies in Radio Broadcast Transmission," by Ralph Bown, D. K. Martin and R. K. Potter; *Proceedings*, I. R. E., Feb., 1926.

The factor α will be recognized to be the absorption factor of the familiar Austen-Cohen empirical formula, which may be expressed as

$$e = 0.009 \frac{\sqrt{P}}{d} \epsilon^{-(\alpha d/\sqrt{\lambda})}$$

in which

P = radiated power in watts,
d = distance in kilometers,
λ = wave-length in kilometers,
α = absorption factor,
e = in volts per meter.

The first term represents the decrease in strength due merely to the spreading out of the waves; the second term, the decrease due to the

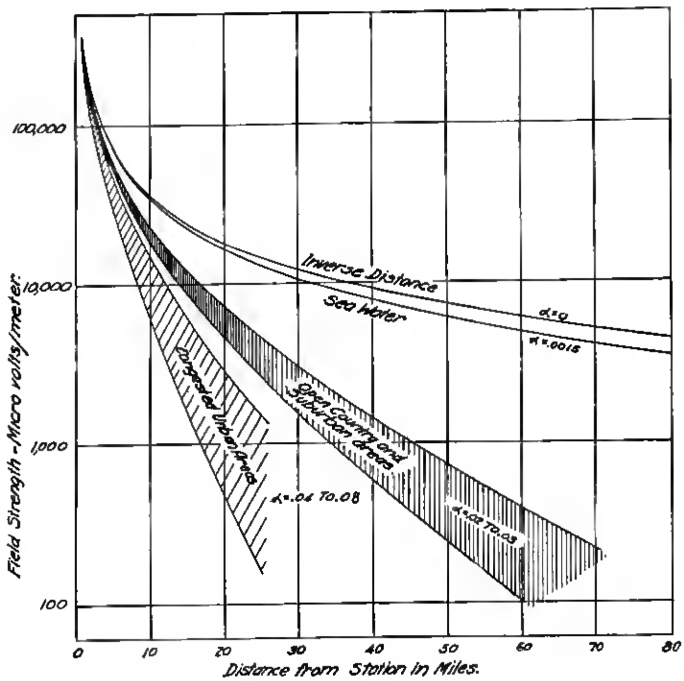

Fig. 3—Effect of the terrain in reducing the field strength of a broadcast transmitting station. 5 kilowatts in antenna, frequency 610 kilocycles, wave-length 492 meters

absorption of the wave energy by the imperfect conductivity of the earth's surface.

The curves given in Fig. 3 are derived from a considerable amount of data taken in the course of field strength surveys of the New York

City and Washington, D. C., areas. The results of some of the earlier of these surveys have already been published.[4]

Actual Distribution in New York City

Fig. 4 presents the results of a detailed survey of the field distribution effected over the New York metropolitan area by Station WEAF located at 463 West Street. The measurements upon which the plot is based were taken in the daytime during the summer of 1925. Measurements were taken at approximately one-mile intervals along each of a series of circular paths concentric with the station, the radii of which increased in steps of approximately five miles. The distribution was studied in even greater detail close to the station and in locations giving evidence of rapid change in field strength. Ferries were utilized to extend the measurements over bodies of water. Manhattan Island was circumscribed on water by measurements made upon a sight-seeing boat. The land measurements were made in all cases outside of buildings at ground level. In the built-up sections of the city they were taken in the middle of streets and street intersections, and in so far as possible in open places. The plot is based upon over 1000 measurements. While these measurements were taken over a considerable period of time, check measurements proved conditions to have remained quite stable and showed, in fact, little variation from measurements made the previous year. The type of measuring apparatus employed, together with certain of the results obtained in earlier surveys, has already been described.[5]

This plot is actually a simplification of a more detailed one. The number of contour lines has been limited to those of round figures for the sake of clarity. The line marked 10,000, for example, traces the locations at which that field strength was observed and beyond which lower values obtained.

This survey shows strikingly that the terrain over a city like New York is anything but uniform electrically; that the variations in the attenuation which the waves experience in different directions and from one area to another distort the distribution pattern from that which we might imagine from the familiar stone in the pool analogy. It is apparent that this simple analogy will have to be amended by conceiving the pool to be beset by various encumbrances causing high attenuations and reflections; and, in fact, also by the presence of

[4] "Distribution of Radio Waves from Broadcasting Stations over City Districts," by Ralph Bown and G. D. Gillett, published in the *Proceedings* of the Institute of Radio Engineers, August, 1924.

[5] See previous reference; also "Portable Receiving Sets for Measuring Field Strengths at Broadcasting Frequencies," by Axel G. Jensen; *Proceedings*, I. R. E., June, 1926.

surface ripples to represent the waves foreign to broadcasting which cause interference. Sight should not be lost, however, of the fact that the contour lines of Fig. 4 represent a two-dimensional section of

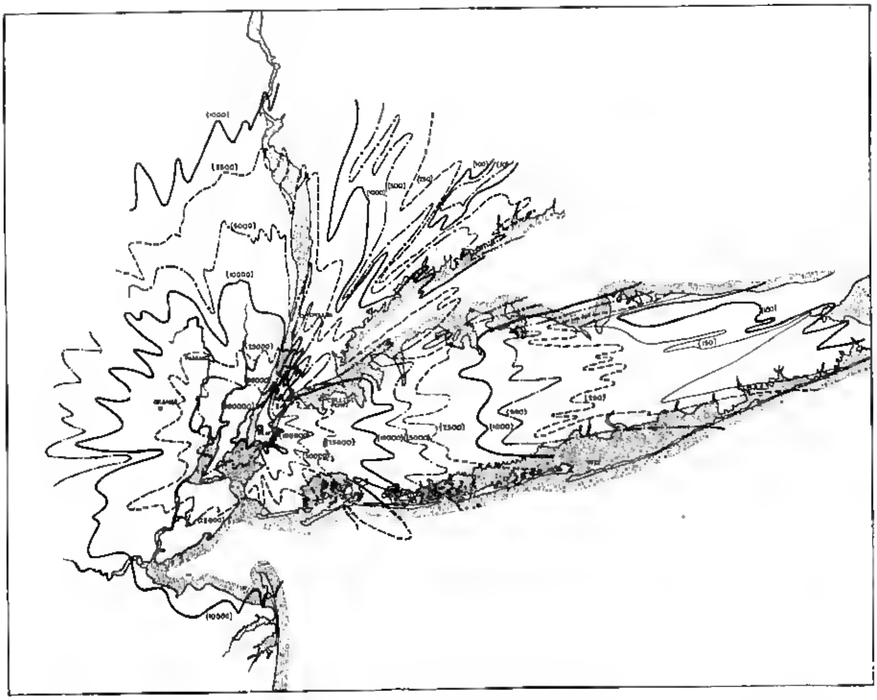

Fig. 4—Field strength contour map of distribution over the New York metropolitan area, effected by Station WEAF. 5 kilowatts in antenna, frequency 610 kilocycles, wave-length 492 meters.

a three-dimensional phenomenon. One should picture the contours as the intersections of the earth's surface with three-dimensional surfaces.

The fact previously referred to that the waves transmitted into Westchester County experience high attenuation is shown by the shape of the contour lines. The irregularity of the lines appears to be due to a splitting of the directly transmitted wave by the high building area and the filling in from the sides of wave energy transmitted along the two sides of the peninsula. Although the conditions in Westchester are quite stable during the daytime, they become unstable at night due, apparently, to the addition of the indirectly transmitted component reflected from above. An experimental study of this interference situation disclosed the fact that the bad quality

obtaining at night in certain parts of Westchester was due largely to a rapid frequency modulation of the broadcast transmitter. The frequency fluctuation of the transmitted band apparently caused the direct and indirect transmissions to slip in and out of phase rapidly. The use of a master oscillator control for insuring stability of frequency greatly improved matters, but evidence still remains of what might be called the normal night-time fading.

Another interesting effect which stands out in this map is the high attenuation of the wave-front transmitted over Long Island as compared with that which pursues the path of Long Island Sound and that of the ocean front to the south. The field over the eastern half of the island is contributed to by the water-transmitted waves from either side, giving rise to interference patterns similar to those in Westchester County.

A question which naturally arises is that of how strong a field, as measured in this way, is required for satisfactory reception. It is too early in the art to answer this question very definitely, for it depends first upon the standard of reception which is assumed, with respect to quality of reproduction and freedom from interference; and second upon the level of the interference. The interference, both static and man-made, varies widely with time and with location. It is therefore obviously impossible to give anything more than a very general interpretation of the absolute merit of field strength values. Observations made by a number of engineers over a period of several years in the New York City area, having in mind a high standard of quality and of freedom from interference, indicate the following:[6]

1. Field strengths of the order of 50,000 or 100,000 μv./m. appear to be about as strong as one should ordinarily desire. Fields much stronger than this impose a handicap upon those wishing to receive some other station.

2. Fields between 50,000 and 10,000 μv./m. represent a very desirable operating level, one which is ordinarily free from interference and which may be expected to give reliable year-round reception, except for occasional interference from nearby thunder storms.

3. From 10,000 to 1000 μv./m. the results may be said to run from good to fair and even poor at times.

4. Below 1000 μv./m. reception becomes distinctly unreliable and is generally poor in summer.

5. Fields as low as 100 μv./m. appear to be practically out of the picture as far as reliable, high quality entertainment is concerned.

[6] See also the paper by A. N. Goldsmith, "Reduction of Interference in Broadcast Reception," *Proceedings*, I. R. E., October, 1926.

Such fields, however, may be of some value for the dissemination of useful information such as market reports, where the value of the material is not dependent upon high quality reproduction.

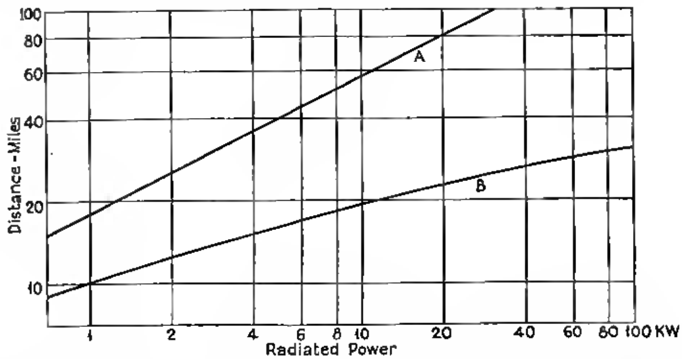

Fig. 5—Showing the increase in radiated power required to increase the range at which a field of 10,000 μv./m. is delivered. Curve *A* without absorption and curve *B* with absorption.

It is seen from the preceding three figures that a 5 kw. station may be expected to deliver a field of 10,000 microvolts some 10 to 20 miles away and a 1000 microvolt field not more than 50 miles. From this it will be evident that the reliable high quality program range of a 5 kw. station is measured in tens of miles rather than hundreds.

Higher Power Transmitting Stations Required

Rough though this interpretation of field strengths is, it indicates clearly the need which exists for the employment of higher transmitting powers. The range goes up with the increase of power disappointingly slowly. Even were no absorption present in the transmitting medium, the range in respect to overcoming interference would increase only as the square root of the increase in power. This is shown in the curve *A* of Fig. 5. It shows that a station which actually radiates five kw. of power would deliver a 10,000 μv./m. field at about 40 miles, a 20 kw. station the same field at distance 80 miles. Actually with absorption present the distances are less. This is shown by the curve *B* which gives the corresponding relations for the absorption observed for suburban and country terrain. To extend the 10,000 microvolt field from some 15 miles out to 30 miles would necessitate an increase in the radiated power from about five to 100 kw.

It is apparent from these relations that radio broadcasting is today underpowered; that the common 0.5 kw. station is entirely too small to serve large areas adequately, and that the more general use of

powers of the order of five kw. and even 50 kw. is decidedly in order. Such increases in power will be required if the broadcasting art is to be advanced to meet the higher standards of the future. The fact should be recognized that no greater interference between stations will be caused by the higher power levels, providing the increase in power is general among all stations. The interference difficulty arises in particular cases where one station suddenly makes a large increase and the others remain at their previous low power levels.

Mention should perhaps be made that the effect of raising the transmitter power in increasing the level of the *detected* signal is greater than would be inferred from the discussion above. This is because of the square-law action of the detector. In other words, the detector output reflects the increase in power of the carrier as well as the side band. In overcoming interference it is only the increase in side-band power which counts.

The ideal broadcast system from the transmission standpoint would be one in which the carrier is not transmitted from the sending station but is automatically supplied in the receiving sets themselves. This would save power, would reduce interference between stations and would reduce fading. It will be recalled that this system is being used to great advantage in the transatlantic radio telephone development. The practicability of employing it in broadcasting will depend upon receiving set development,—upon the economy with which carrier-generating receiving sets can be made and the ease with which the carrier frequency can be set and maintained with the necessary accuracy.

Transmitting Station on Tall Building

The location which naturally suggests itself for a broadcast station intended to serve a city is that of its center. Such a location might be expected to deliver the greatest strength of field to the greatest numbers because of the coincidence between high field strengths and high density of population. The other possibility, of course, is that of placing the station outside of the city, with the object of obtaining a better "get-away" condition, of covering a larger area and of laying down a more uniform, if less strong, field over the city itself. Instances of both of these types of locations readily come to mind. WEAF is a good example of a station located near the center of a large city. The results of a study which has been made upon the effect of moving the station to other possible locations are given below.

Before coming to this, however, there is another important factor to present and that is the effect of placing the transmitting station

upon a tall building. In locating a station near the center of a large city it is natural to select a tall building for the station site. This has been done for a number of stations in various cities. The operation of WEAF, when known as WBAY, was first attempted from the top of the 24 story long-distance telephone building located at 24 Walker

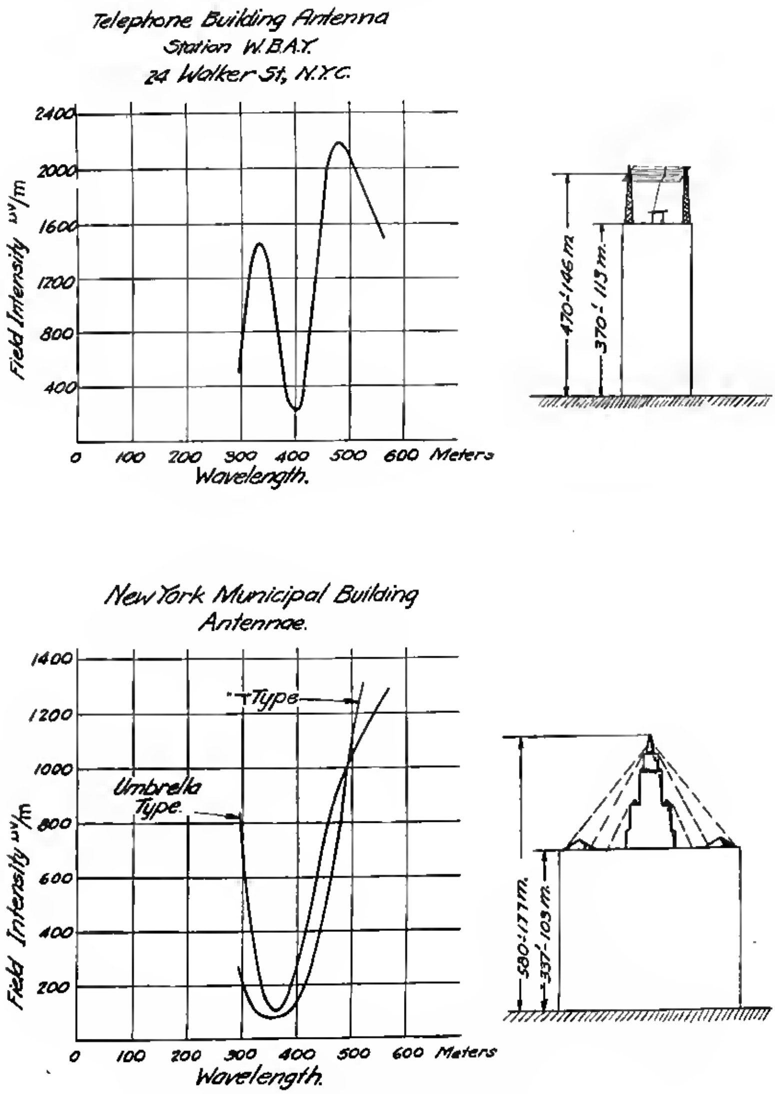

Fig. 6—The selective radiation characteristic of transmitting antennas on tall buildings

Street, New York City. It was found that with the limited wave-length range then open to broadcasting, radiation from the station was relatively poor. Measurements of the field strength delivered to a field laboratory located at Cliffwood, N. J. (on lower New York Bay), were made which gave the results shown in Fig. 6. The radiation was found to be sharply selective with respect to frequency, and to drop to a very low value at 400 meters. This happened to have been the wave-length assigned to the station at the time. When it became possible to shift the station to a longer wave-length, radiation was greatly improved, as indicated by the curve. The study made on this station was the first to disclose the fact that it is possible to have the building too high for the efficient radiation of certain frequencies.

As a result of this work it was possible to predict the probable occurrence of a similar effect in the case of a station which the City of New York desired to establish on the Municipal Building. Temporary antennas were erected and radiation from them measured at Cliffwood, N. J., using a transmitting oscillator of 100 watts. The results of these measurements are given in Fig. 6. The radiation was found to be a minimum in the vicinity of 360 meters, which was very nearly the wave-length which at that time was to have been assigned to this station. The establishment of the station at this location obviously could not be recommended until at a subsequent time when a longer wave-length was made available. The station is now operating on 526 meters, which is seen to be fairly well up on the radiation curve.

In both of these cases experiments were made with a number of different antenna arrangements and with different methods for driving the antenna and effecting the ground connection. None of the modifications, however, materially shifted the frequency of minimum radiation. This minimum occurs when approximately one quarter of the wave-length equals the height of the building. Measurements made upon buildings of lower heights have shown that for the usual broadcast wave-lengths heights of the order of 200 ft. are entirely satisfactory. The antenna of WEAF (which has been located for the past several years on the building of the Bell Telephone Laboratories, 463 West Street, New York), and that of WCAP, in Washington, are on buildings which put them at about this height above the street. They both have normal radiation characteristics.

Distribution from Suburban Locations

In order to determine the distribution over New York City which might be effected from locations outside of Manhattan Island, experi-

mental transmitting stations were established at each of several suburban locations. Use was made of an automobile truck equipped with a ½ kw. broadcast transmitter and provided with a transportable

Fig. 7—Transportable field transmitting station

mast. The experimental transmitter as set up at Secaucus, New Jersey, is shown in Fig. 7. Measurements of the field strength delivered from each of the locations chosen were made over practically the entire metropolitan area. The results of these tests are given in Fig. 8, in comparison with those of transmission from the normal location of WEAF at West Street and from the earlier location at 24 Walker Street. The measured field strengths have been adjusted to correspond to the 5 kw. transmitter of the West Street station.

The smaller irregularities in the West Street curve as compared with the others are due to the greater detail with which these measurements were made. The curves should be compared merely with respect to their major contour characteristics. The inner contour line is for 50,000 μv./m. and the outer line for 10,000 μv./m. Actually, the measurements were made in sufficient detail to enable other contour lines to be drawn, but these have been omitted for the sake of simplicity.

The radiation from Secaucus will be seen to deliver a strong field to Manhattan Island, the most densely populated section, and, in general, to encompass the rest of the city quite well within the 10,000 μv. line. The irregularity in Queens County evidently represents the shadow cast by the tall building area on Manhattan Island.

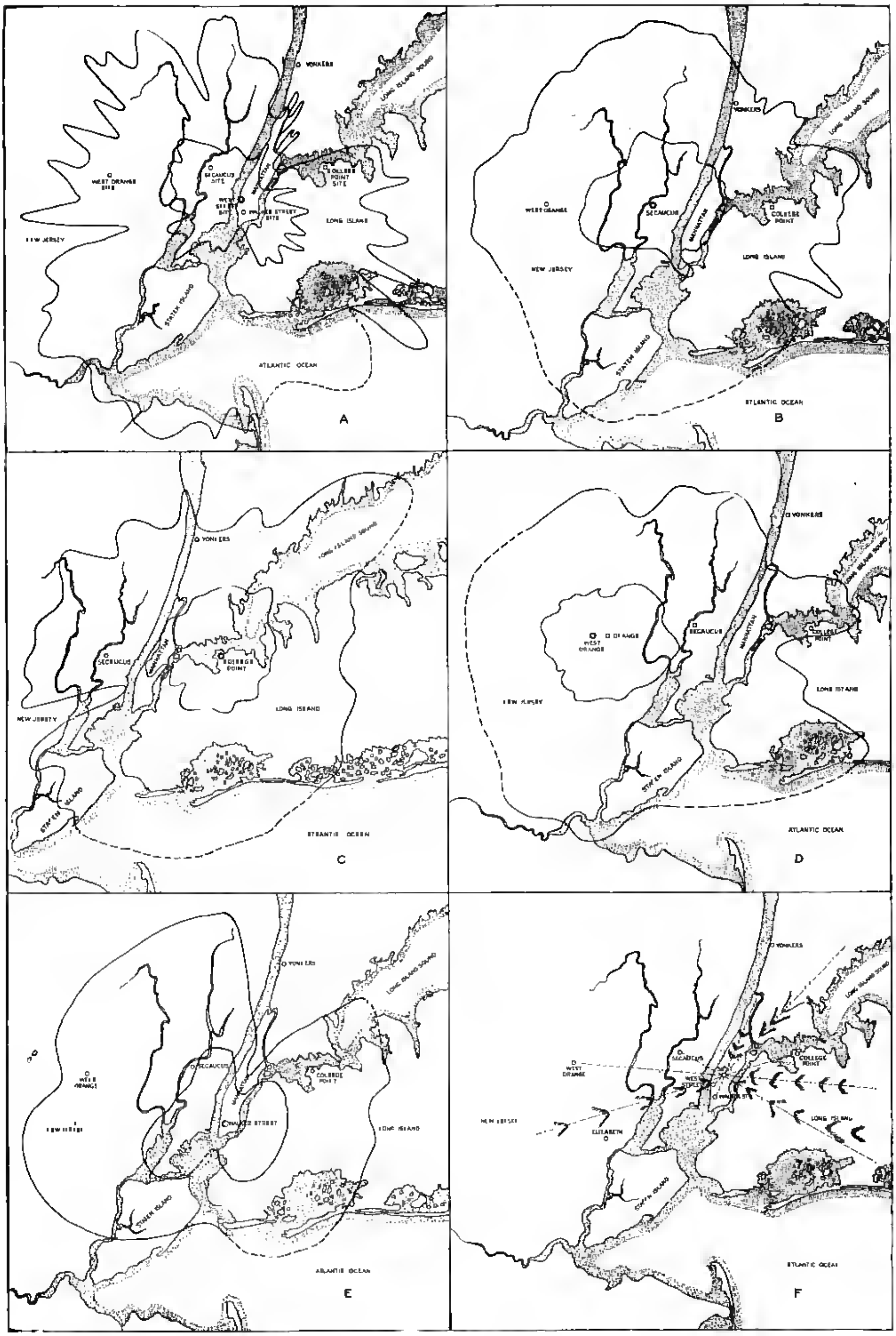

Fig. 8—Effect upon the field distribution of moving the transmitting station to suburban locations

A—463 West Street, New York City
B—Secaucus, N. J.
C—College Point, Long Island, N. Y.
D—West Orange, N. J.
E—24 Walker Street, New York City
F—Composite figure showing main shadows and center of obstacle

The distribution effected from the College Point location appears to be generally good. It does not cover the New Jersey suburbs as strongly as might be desired. The shadow cast by the Manhattan Island high buildings lies through Jersey City and lower Newark.

The distribution from the West Orange site appears to be somewhat less favorable. It is not sufficiently close in to deliver with moderate power a very strong field to the center of the population, nor is it sufficiently far out to avoid subjecting a considerable population in the immediate vicinity of the station to an excessive field were high power employed. The indent in the 10,000 μv. line in northern Queens is the shadow of the Manhattan buildings.

The distribution shown for the Walker Street location is seen to be generally similar to that of West Street. The curve presents a smoother appearance than the others because less data were taken in this one of the earlier surveys. The shadows cast to the north and to the south by the two areas of high buildings are prominent. Actually, a close examination of the contour lines reveals a noticeable angular displacement in the Westchester shadow as between Walker Street and West Street, Walker Street transmitting better up the Sound and West Street better up the Hudson. West Street turns out to be somewhat the better of the two.

The last diagram of the series brings together the shadows as determined from the several transmitting sites and shows that they project back to a common general center which locates at approximately 38th Street and Broadway, which corresponds quite well with the center of the up-town tall building area.

Relation between Wave Distribution and the Distribution of Listeners

The merit of a given distribution pattern obviously depends upon the relation which exists between it and the distribution of the receiving sets themselves. In order to study this relation more closely, the relative distribution of receiving sets was approximated by taking the distribution of residence and apartment house telephones in each of the central office districts of the metropolitan area, excluding the commercial telephones. It was assumed that the receiving set distribution is proportional to that of the telephones. For a given survey the field strength representative of each central office district is known. By assembling the figures for central office areas receiving like field strengths, and by doing this for the whole range of field strengths measured, an accumulative percentage curve may be derived which shows the percentage of the total number of receiving sets included within the contour lines of successively weaker fields.

Curves of this kind for each of the several surveys made are shown in Fig. 9. It will be seen that for field strengths of 10,000 μv./m. and better, the Secaucus and College Point transmitting sites include about 80 per cent of the receivers, that the West Street and West

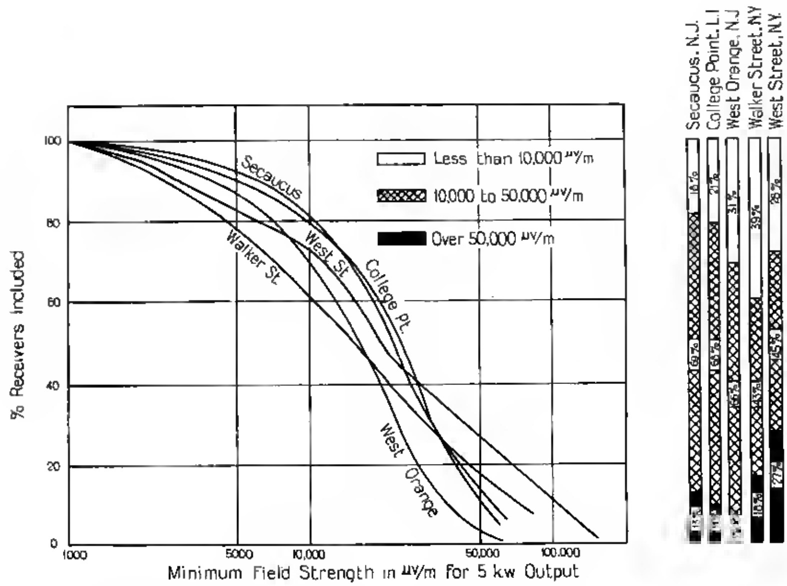

Fig. 9—Percentage of receiving sets in metropolitan area included within various strengths of field for each of the transmitting locations of Fig. 8

Orange sites include around 70 per cent and Walker Street about 60 per cent. These curves are further analyzed in the chart to the right of the figure to show in each case the proportion of the listeners which may expect to receive

a. less than 10,000 μv./m.,
b. between 10,000 and 50,000 μv./m.
c. over 50,000 μv./m.

It is seen from this that a location to the east or west of Manhattan Island would give a material improvement in uniformity of distribution as compared with a location on Manhattan Island. Had it been possible to include a station on Manhattan Island located farther north than is either West Street or Walker Street and included within the area of high steel buildings, it is probable that the corresponding curves for such a location would show the poorest distribution of the series.

The survey work described above did not go so far as to include a study of the distribution effected from a location well outside of the suburbs. The philosophy of such a location is, of course, that of attempting to encompass within the range of the station a wide-spread area and of so including the city within the area as to effect a more uniform distribution over it than is possible when transmitting from a location within the city. A theoretical study was made of the distribution to be effected from one such location in the general vicinity of Boonton, New Jersey, using attenuations obtained in the other surveys. Such a location would be somewhat similar to that of WJZ at Bound Brook, although the distance from Boonton to New York is less. The figures derived upon the basis of a 50 kw. broadcasting station are as follows:

Field Strength	Percentage of Receiving Sets in Metropolitan Area
Below 10,000 μv./m.	10 per cent
Between 10,000 and 50,000 μv./m.	79 per cent
More than 50,000 μv./m.	11 per cent

These figures show a good concentration in the most desirable field strength values. They should be discounted somewhat because they

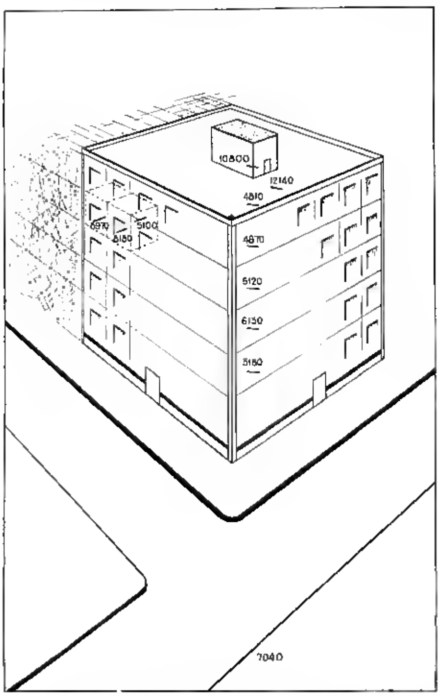

Fig. 10—The effect of non-steel apartment house building in shielding radio reception within it

are based upon symmetrical distribution and do not include the effect of irregularities, which an actual survey probably would reveal.

Receiving in Apartment Houses

The surveys described above disclose the field strength distribution as measured generally in the streets and open places. It does not disclose the details of field distribution in the immediate vicinity of a

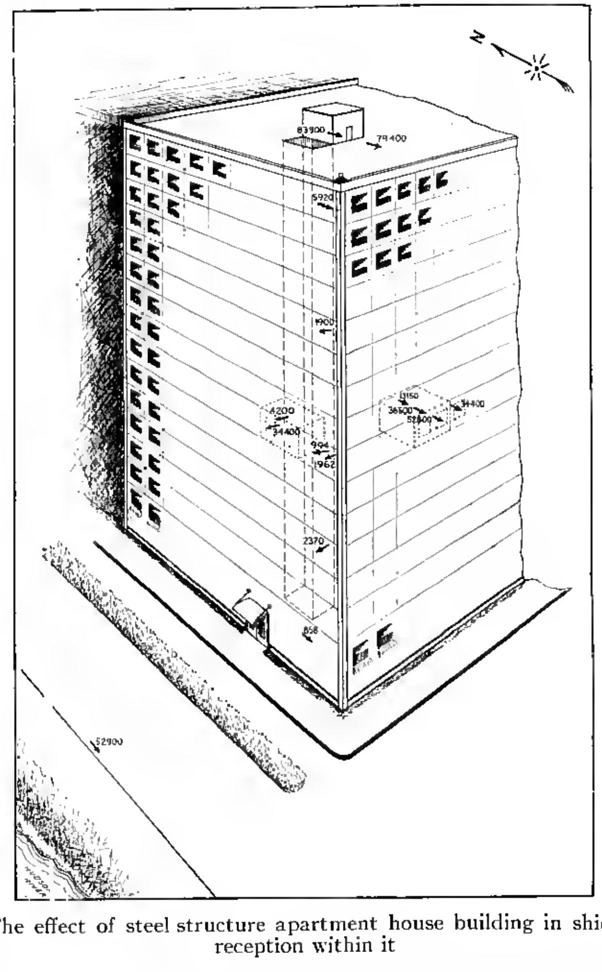

Fig. 11—The effect of steel structure apartment house building in shielding radio reception within it

receiver. Perhaps the most difficult situation is that of the large apartment house, particularly where it is desired to receive by means of an indoor antenna. Two effects are encountered: First, the reduction in signal strength by virtue of the shielding effect of the building;

and second, the existence of a relatively high noise level caused mainly by radio-frequency interference from electrical systems within the building.

The results of a few observations upon signal strength reduction within two buildings are presented in Figs. 10 and 11. Fig. 10, for a non-steel building, shows the field to be roughly halved. In the case of the steel structure building depicted in Fig. 11, the interior field is found to be reduced to as low as a few per cent of that outside the building. For outside rooms, the field strength near the window was found to be about eight times that further in the room. Such severe shielding effects obviously call for picking up the wave energy outside the building and conducting it to the receiving sets by wire circuits, preferably by shielded circuits, in order to protect against local interference.

Multi-Station Operation

The discussion given above has been directed chiefly to the relations which might be called internal to a single-channel radio broadcast system. Actually, of course, broadcasting involves the use of the common transmitting medium for a number of channels. This brings with it the problem of frequency selectivity and raises the question of the capabilities of the various types of radio receiving circuits.

In order to throw some light upon this important factor, measurements have been made upon a sample or two of each of a number of different types of radio receiving circuits. The measurements were made in the laboratory,[7] simulating as closely as possible the conditions under which the receiving sets would be used. The curves of Fig. 12 show the reduction which is to be expected in the detected audio-frequency current, were the receiving set tuned to a transmitting station on 900 kc., and the transmitting station then shifted in frequency by the amounts given along the abscissa. In this curve the reduction in current is indicated both as a ratio and in TU, which is a convenient way of indicating power ratios. The relation between TU and current ratio with a given impedance is indicated in the figure. Thus, for a carrier 40 kc. off from the one to which the set is tuned, the single-circuit, non-regenerative type of receiver

[7] The method consists in establishing a small laboratory transmitter and modulating it with a single-frequency tone. The receiving set is tuned to the modulated carrier signal as in practice. The gain or sensitivity of the receiver and its coupling with the transmitter are adjusted to produce normal load upon the detector tube. With the receiving set left at this adjustment the frequency of the radio transmitter is shifted each side of the original single frequency in 10 kc. steps throughout a range of 50 to 100 kc. For each of the offside frequencies the reduction caused in the detector output current is measured, this being an indication of the receiving set selectivity.

showed a cutoff of only 20 TU, corresponding to an audio-frequency current reduction to 0.1 that of the value at resonance. The curves will

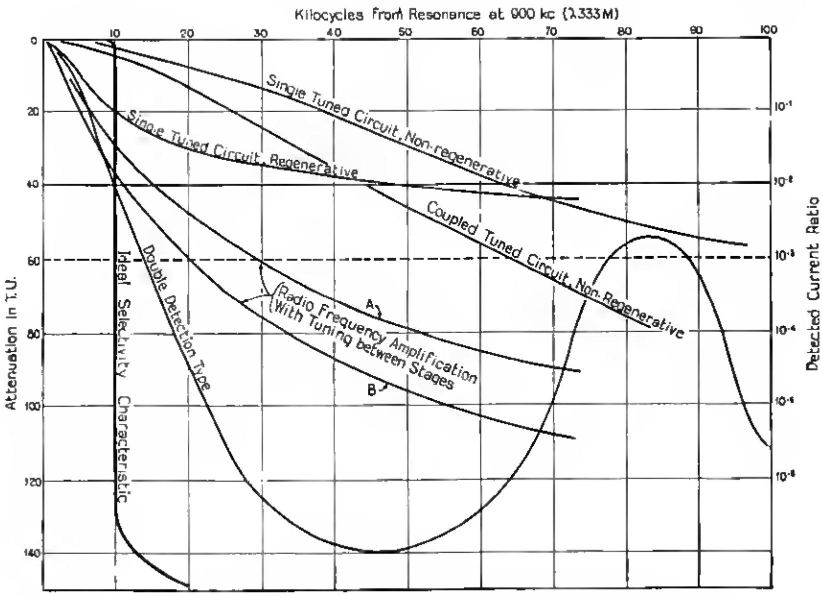

Fig. 12—Receiving set selectivity characteristics as measured from samples of receivers having different types of selective circuits

be seen to group themselves more or less into three classes in the order of their selectivity merit as follows:

1. The single-tuned circuit (non-regenerative and regenerative), and the combination of two tuned circuits coupled together.

2. Circuits employing radio-frequency amplification with tuned circuits between stages.

3. The double-detection or superheterodyne type of circuit.

The curve for the double-detection type of circuit shows a "come-back" which represents the familiar double-tuning effect. (Incidentally, the admittance of this particular set, which was not a commercial set, needs to be reduced by the use of more selectivity at the radio frequency.)

For comparison purposes there has been added to the figure the curve marked "ideal selectivity characteristic," in accordance with which the receiving set would pass without attenuation all frequencies up to 5000 or 10,000 cycles and would cut off abruptly all frequencies without this band. Attention is first called to the fact that the various circuits attenuate *within* the desired transmission band of

five or ten kilocycles. This means the higher frequency components of the side band will be reduced by the amounts indicated (after detection) with corresponding distortions of the reproduction. The distortion will be seen to be greater for the more highly selective sets. This follows from the nature of sharply tuned circuits. Selective circuits, capable of approximating the filter type of characteristic, are to be desired.

In comparing these selectivity characteristics, it is necessary to have in mind the amount of differentiation between the desired and the undesired signal which is necessary for the avoidance of interference. Each of the signals may be considered as fluctuating during the rendition of the program over a considerable range of volume which centers about some average value. The amount of differentiation required between the average values obviously depends upon the range of the fluctuations involved and upon the standard which is assumed with respect to freedom from interference. Experience with loud speaker reproduction indicates that ordinarily a level of the average of the undesired signal 40 TU lower than that of the desired signal, while not giving noticeable interference at times when the desired signal is strong, does permit the undesired signal to "show through" during times when the program rendition is weak. Reducing the undesired signal to 60 TU below the desired signal prevents this interference for the volume ranges which are now commonly transmitted. If the future art brings with it the requirement of following greater swings of volume, a further reduction in the undesired signal may be necessary. The value of 60 TU has been dotted in across the chart of Fig. 12, in order to show readily the frequency separation at which the different selective circuits give this attenuation of the undesired signal. This is upon the basis that the field strengths of the two signals are equal. Inequalities in field strength require that the 60 TU value be increased or decreased by the amount of the inequality as measured in TU.

The frequency interval which has been recommended by the National Radio Conferences for stations in the same zone is 50 kc. It is evident from the curves that sets equipped with the simpler types of tuned circuits will be subject to some interference between stations thus separated even if the receiver is so favorably situated as to receive equal field strengths from the desired and undesired stations. The selectivity of the other types of receiving circuits is seen to be sufficient to avoid interference under these conditions and allow some margin for overcoming inequalities between the fields. Such inequality becomes great where the attempt is made to receive distant

stations through the effect of local stations. Assume, for example, that the listener receives 50,000 microvolts from a local station and 500 microvolts from a distant station to which he desires to listen. There exists a 100 to 1 or 80 TU disadvantage to be overcome. When added to the 60 TU needed for crosstalk clearance, the total selectivity requirement, as measured in terms of detected audio current, becomes 140 TU, or a current reduction of the order of 10,000,000 to 1. The need for a high degree of selectivity is therefore apparent. The impracticability of receiving distant stations removed in frequency from local stations by any such narrow margin as 10 kc. is also obvious.

The effect of receiving set selectivity in increasing the area over which a station may be received without interference from a second station is illustrated in Fig. 13. The two stations are assumed to be of equal powers so that they deliver equal field strengths to receiving stations along a line midway between them. Receiving sets so located are required to have an amount of selectivity called for by the crosstalk margin itself, say 60 TU. On the desired-station side of this line the selectivity may be less; this is the region where poorly selective receivers can be employed. On the undesired-station side of the center line the selectivity requirements are greater. The noninterference area is pushed up closer and closer to the undesired station as the receiving set selectivity is improved, as is indicated by areas *A* and *B* of the figure. For example, assume that the selectivity of the receiving set is such as to give a 100 TU cutoff of an undesired station, offset by 50 kilocycles. Sixty TU of this would be required were the two signals of equal strength, so that 40 TU measures the difference by which the undesired signal may be greater than the desired one. The increased area of reception made possible by this additional 40 TU is indicated by that portion of the lower figure which is to the right of the center line and outside of the area *A*. Within the area *A* interference would be suffered. This interference area may be diminished by the use of still greater selectivity. The addition of another 20 TU of selectivity (again as measured in terms of detected audio-frequency current) would reduce the interference area to that within the small area at *B*. The extent to which the selectivity requirement of the receiving set is determined by its location, therefore, is apparent. The conditions which obtain in multistation areas, such as New York City and Chicago, obviously call for a general use of high selectivity sets.

In locating a new transmitting station it should be possible from a knowledge of the relative field strengths of other stations in the vicinity to predict approximately what the interference area will be

for the different types of receiving sets. In this connection there should be recognized the advantage from the interference standpoint which exists in grouping together the broadcast transmitting stations as far as possible in one location, and in equalizing their powers. Such

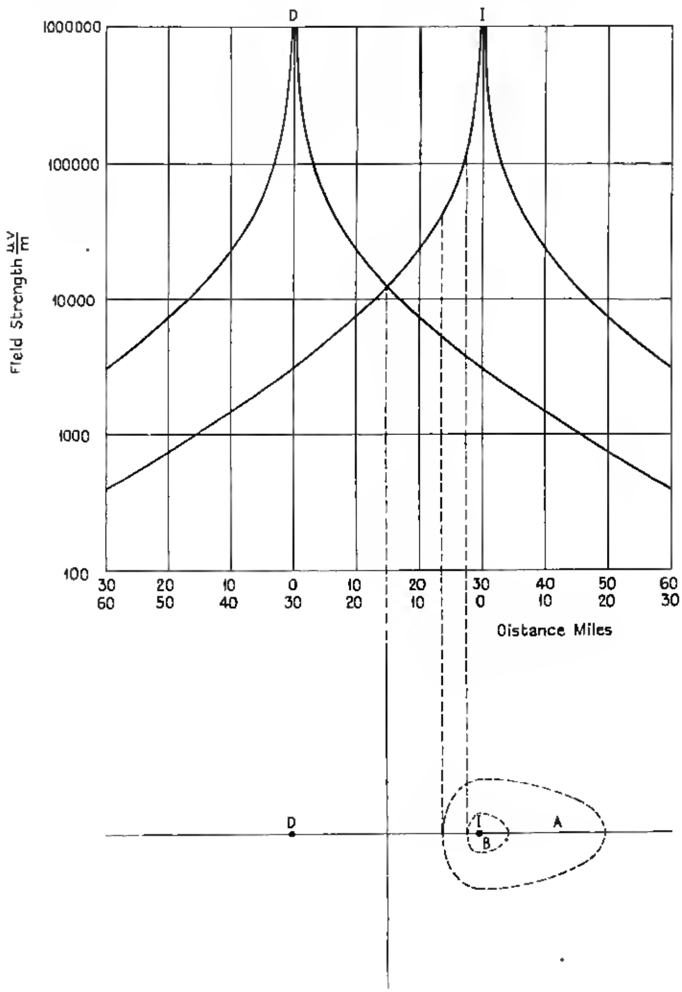

Fig. 13—Showing the greater area over which the more highly selective receiving sets may receive a desired station D and exclude an interfering station I

grouping and equalizing would enable the receivers to obtain substantially equal fields from all of the stations and would minimize the selectivity which they are required to possess. While it is im-

practicable to accomplish this result completely, it is hoped that a better understanding of the interference problem as here outlined and of the mutual advantage to be gained in reducing interference will lead naturally to a better coordination of radio broadcast stations.

Acknowledgment

The data and analyses presented in this paper are the result of the cooperative effort of a number of engineers in both the American Telephone and Telegraph Company and the Bell Telephone Laboratories, Inc. In assembling and presenting the material the writer is acting merely as the spokesman for these development groups. He wishes to acknowledge his indebtedness to his colleagues, particularly to those who have directly participated in the survey work described and assisted in the preparation of the paper, namely, to Messrs. D. K. Martin, R. K. Potter, G. D. Gillett and H. B. Coxhead, and to Messrs. S. E. Anderson and O. O. Ceccarini of the Bell Telephone Laboratories to whom is due the measurement work upon the radio receiving sets.